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(54) **Ceramic band-pass filter**

(57) A dielectric filter is formed from a block of ceramic material with holes extending from a top surface toward a bottom surface. At least the bottom, both ends and one side surface are coated with conductive material. Also, the interior surfaces of the holes are coated with conductive material to form transmission line resonators. The uncoated side surface has an electrode pattern which allows coupling to the filter and between resonators of the filter. The elevation of the electrodes on the side surface between the top and bottom determines whether the coupling is capacitive, mixed inductive and capacitive, or inductive.

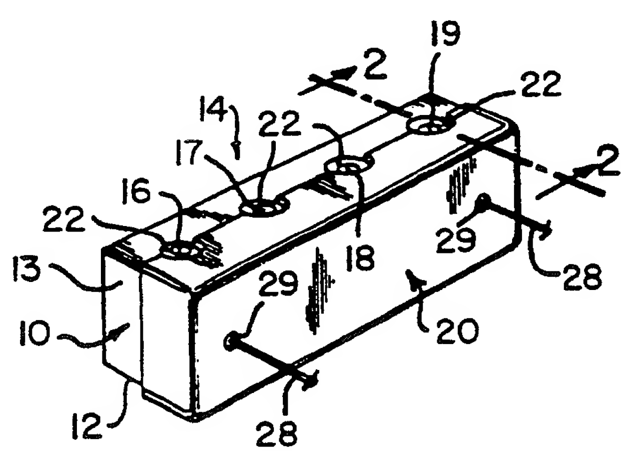

FIG. 1

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can be achieved by means of plates positioned above the open circuit ends of the resonators as shown in U.S. Patent No. 4,028,652 of Wakino et al.

The capacitance can also be achieved by an electrode pattern on the open circuit surface of the dielectric block as shown in the Sokola patent. After the dielectric filter is formed the frequency can be adjusted by removing conductor material near the open circuit end to raise the frequency and at the short circuit end to lower the frequency. This is described in U.S. Patent No. 4,800,348 of Rosar.

With the prior art techniques the coupling into and out of the filter structure, as well as between resonators in a single dielectric block, is generally either capacitive or inductive. Also, when this coupling is accomplished by electrode patterns on the dielectric block, the patterns are typically on the open circuit side. Because of the holes which open onto this side, the arrangement of patterns is limited. Further, electrode patterns on the open circuit side cannot create inductive coupling.

Summary of the Invention

The present invention is directed to the creation of a band-pass filter made of a dielectric material, which filter has electrical properties that are easily adjusted over a wide range of values without altering the dielectric body of the filter or the dimensions of the mold used to produce the body. This is achieved by locating, at least in part, an electrode pattern for controlling inter-resonator coupling on a side surface of the dielectric block, instead of on the top surface.

An electrode pattern on the side of the dielectric block allows the inter-resonator coupling to be capacitive, inductive or mixed capacitive and inductive in the same filter block. In addition, coupling into or out of the block can also be achieved by means of electrodes on the side surface so that input/output coupling may also be capacitive, inductive or mixed. By utilizing the side surface of the dielectric block, the greatest surface area on the block and the area with the least number of obstructions, e.g. holes, is used for the electrode pattern. As a result, the maximum amount of design flexibility is provided to the filter designer. With this design flexibility the designer can change the filter characteristics, e.g. the bandwidth and center frequency, by changing the electrode pattern on the side of the filter block and without changing the mold in which the block is cast or the physical dimensions of the finished block. All that has to be done is to change the mask used to apply the coating of conductive material.

Since mixed capacitive and inductive coupling can be used, the filter may be designed with imaginary zeros. Consequently, the number of resonators for equivalent performance can be reduced by about one-third. This allows for a corresponding reduction in the length of the filter.

In an illustrative embodiment of the filter a block of ceramic material is molded in the form of a parallelepiped with top, bottom, side and end surfaces. A number of holes, e.g. four (4), are created in the block extending from the top or open circuit surface toward the bottom or short circuit surface. The bottom surface, both end surfaces and one side surface are completely covered with conductive material. The top surface may be uncoated or it may be mainly covered with conductive material, except for an area around each hole which is left uncoated. Conductive material is coated inside the holes and is connected with the conductive material at the bottom surface to form four (4) transmission line resonators.

The uncoated side surface contains an electrode pattern that is used to achieve coupling into and out of the filter block, as well as to control coupling between the four (4) resonators. The pattern may take the form of loops located near the base of the input and output resonators, i.e. the endmost resonators. One end of each loop is connected to a lead, either an input or output lead, and the other end is connected to the conductive material near the bottom surface. This arrangement provides coupling into and out of the filter.

An electrode projecting from the loop extends from the top of the loop at the endmost resonators to the next resonators to provide inductive coupling between them. An isolated electrode pad is located between the two middle resonator to capacitively couple them. Further, electrode strips extend from the conductive material near the top to the conductive material at the bottom, and extend between the projecting electrodes and the pad. These strips control the amount of capacitive coupling achieved with the pad.

Conductive material is spaced at a distance from the side of the dielectric block with the electrode pattern. This material may be in the form of a conductor on the opposite side of a printed circuit board to which the filter is mounted or it may be a metal cover. When a printed circuit board is used, the conductive cover can be etched at the same time other patterns are formed. Further, instead of coating the electrode pattern on the side of the dielectric, it can be formed on the side of the printed circuit board in contact with the dielectric. This results in a savings in time in the formation of the filter.

If a metal cover is used over the electrode pattern, it may be assembled to the filter block in such a manner that the spacing or air gap between the side and the cover is adjustable. Adjusting the size of the air gap is another means of adjusting the bandwidth of the filter to fine tune it.

With the structure of the present invention, it is only necessary to alter the electrode pattern or coupling design on the side wall of the filter block in order to change the frequency response of the filter and the maximum points of attenuation formed at the upper and lower sides of the desired pass band of the filter. In practice this means that a few standard sizes of ceramic bodies or blocks can be used and, for a particular application, an electrode pattern is selected to create a filter with desired characteristics. Also, a much smaller filter can be formed.

Purely capacitive coupling to a resonator or between two resonators can be achieved by using a detached conductive coupling pad, for example coupling design 34 in Fig. 3, which is located between resonators 17 and 18. Extensions 32 and 36 of inductive coupling designs 31 and 35, extend between the resonators 16 and 17 as well as resonators 18 and 19 to create a mixture of inductive and capacitive coupling between these resonators. This type of mixed coupling between two resonators can also be realized by simultaneously using separate inductive and capacitive coupling designs.

Inductive coupling is the greatest close to the bottom end of the resonator, where the magnetic field of the resonator is the strongest. On the other hand, the capacitive coupling is the greatest close to the top end of the resonator, where the electric field is the strongest. In this way, both inductive and capacitive coupling can be adjusted by either changing the size of the coupling design or by changing the elevation of the coupling design along the side surface 15. For example, the widening and elevating of the inductive coupling pattern, decreases the inductance of the design, thus decreasing the coupling to the resonator. Equivalently, increasing the size of the capacitive coupling design or the elevating of it's position, increases the coupling to the resonator.

The low end of the pass band can be affected by capacitive coupling and the high end of the pass band can be affected by inductive couplings. Since, by using inductive couplings, a low-pass type of filter can be achieved directly, the band-pass filter of the present invention can be realized with four transmission line resonators, while a minimum of six transmission line resonators was previously needed.

In prior filters, it was necessary in order to produce steep attenuation at the edge of the pass band, and hence improve the selectivity of the filter, to create zeros at the upper and lower edges of the pass band. These zeros were created by additional resonators. However, the mixed inductive-capacitive coupling achieved by electrodes 31, 32 or 35, 36 of the present invention permits the creation of imaginary zeros. Thus, the two extra resonators required in the prior art to form the zeros at the upper and lower side of the band, can be eliminated with the present invention and the overall size of the filter can be reduced.

The creation of imaginary zeros is actually a phase cancellation technique as described in Nagle, "High-Frequency Diversity Receiver From the 1930's", Ham Radio (April, 1980) pages 40-41. The basic idea is to have two coupling paths which, at a predetermine frequency, are opposite in phase, but equal in amplitude. In the present context there is magnetic coupling between the resonators through the dielectric body. To achieve phase cancellation, there is also coupling via electrodes 32, 36. These electrodes 32, 36 are arranged so that at particular frequencies, e.g. the upper and lower edges of the pass band, the signals travelling over the electrodes cancel the signals travelling through the body. This cancellation has the same effect as a band elimination filter or zero, but does not require a separate resonator. Hence it may be referred to as an "imaginary zero".

There can be more than two imaginary zeros. Also, instead of being located on either side of the pass band, they may all be located above or below the pass band.

Fig. 5A shows an equivalent circuit for a two resonator 61, 63 dielectric filter. Fig. 11B in solid lines shows the transfer characteristics for this filter. By utilizing the electrode pattern on the side surface, a capacitive connection 60 can be established between the input and output terminals 65, 67. The result of this capacitive coupling is to create imaginary zeroes at the edges of the pass-band. Thus, the transfer characteristic is changed to match that shown in dotted line in Fig. 5B. This sharpening of the pass-band due to the imaginary zero allows fewer resonators to be used.

If the connection of electrodes 31, 35 to ground strips 33, 37 is broken the input/output pattern becomes capacitive This will change the position of the imaginary zeros, but they will still exist.

Fig. 3 is meant only to illustrate the use of the coupling designs on the side surface of body 10, and an exemplary shape. The shapes and sizes used in a particular application are determined by the desired electrical specifications and the desired method of realization of a particular filter.

In reference to Fig. 1 and 2, the side surface 15 of body 10 with the electrode pattern coupling designs on it, is covered with a moveable box-like metal cover 20, whose side surfaces, 20a and 20b are partially pushed onto the top and bottom surfaces 11, 12 of body 10 in contact with electrical conductive plating 21 which covers them. Thus cover 20 surrounds the side surface 15 which has the coupling design of its. The electrically conductive surface of the cover 20 is equivalent to plating 21. As a result, it provides a conductive cover on the side of the resonators and assures that the resonators function properly.

On the inner surface of the sides of cover 20 are shoulders 20c, which come against the side surface of the body 10, thus determining the distance between the inner surface of cover 20 and the side surface 15. In the primary embodiment of the invention, there is an air gap 25 between the cover 20 and the side surface 15. By moving cover 20 and changing the size of the air gap 25, the bandwidth of the band-pass filter can be adjusted. If desired, the air gap 25 can be partially or wholly filled with a suitable dielectric material.

In addition, in cover 20, there are one or more openings 29, through which coupling leads 28 extends inside the cover for connection to the coupling designs on the side surface 15 of body 10.

Fig. 4 presents a cross-sectional diagram of another embodiment of a band-pass filter according to the present invention. The filter of Fig. 4 is equivalent to the band-pass filter of Figs. 1 and 2, and the same reference numbers used in Figs. 1 and 2 are used in Fig. 4 to indicate the same elements. The mbodiment of Fig. 4 differs from that in Fig. 2 in that the side surface 15 of body

exact value desired. With the arrangement of Fig. 9B, the resonators are designed to have the exact frequency which is desired. If the frequency is a little low or a little high, in practice, the material can be moved from conductors 41 and 43, respectively, to tune the frequency exactly.

As an alternative, the frequency can also be reduced by removing a portion of the dielectric material from the top surface 11 adjacent the resonator. A gouging out of this material, as at 45, results in a increasing of the frequency. Further, by adding dielectric material adjacent a resonator on the upper surface 11, the frequency of the resonator can be lowered.

The pattern shown in Fig. 9C is basically the same as in Fig. 9A, except it includes strip 43 with tuning tabs 78. These tabs can be scratched off to affect tuning without disrupting the grounding strip 43. While these techniques for tuning the frequency of the resonators are preferred, other tuning techniques can also be used.

Two filters according to the present invention can be combined to form a duplex filter. A block diagram of such an arrangement is shown in Fig. 10A in which filter 50 is connected between a transmitter and an antenna 51 and a filter 52 is connected between a receiver and the antenna 51. The pass band of each of these filters is offset from each other such as shown, for example, in Fig. 10B, where the transmitter pass band is located below the receiver pass band. However, the opposite arrangement is also possible.

The connection 53 between the filters and the antenna 51 may be made a quarter wavelength long in order to achieve phase and impedance matching. Alternatively, reactive components can be included in lines 53, so a full quarter wavelength line is not needed.

A reactive component for combining two filters to form a duplexer may be formed by a portion of the electrode pattern 30 on the side surface of one or both of the resonators. In such a case, the block of ceramic material may be mounted in a metal bracket and installed in a printed circuit board without the need for discrete reactive components. Also, if a quarter wavelength structure is needed for combining filters 50 and 52, this structure can be provided in the form of an electrode pattern on the sides of the dielectric blocks.

In addition to using two band-pass filters to achieve a duplexer structure, a band-pass and a band-stop filter may also be used. The transfer characteristic for this is shown in Fig. 10C. The advantage of using a band-stop filter is that it has the same insertion loss and isolation for the receiver band with three resonators, as does a four resonator band-pass filter. If the receiver pass-band filter is made using phase cancellation according to the present invention, only four resonators are needed, as opposed to the six resonators in a conventional band-pass filter. Thus, the duplexer structure using a band-stop arrangement has a total of seven resonators compared to twelve resonators using conventional band-pass arrangements.

The circuit pattern shown in Fig. 9A is an arrangement for a receiver band-pass filter of a duplexer, i.e. for filter 52 of Fig. 10A. The input and output pads 72 capacitively couple to resonators 16 and 19, respectively. They also provide inductive coupling between resonators 16, 17 and resonator 18, 19 by means of grounded strips 74. These connections create the phase cancelling phenomenon that results in imaginary zeros. Pads 76 are connected by an external wire and allow capacitive coupling between resonators 17 and 18. The grounded strips 77 help to limit capacitive coupling between various portions of the electrode pattern 30.

The pattern of Fig. 9B is for the transmitter filter 50 of Fig. 10A. It has capacitive input terminals or electrode pads 54 at the input and output ends. The pad at the output end is shown connected to a ground strip via a conductive lead 55. This lead, however, is made small so that at radio frequencies it does not diminish the capacitive effect of pad 54. Strip 55 is preferably a quarter wavelength long so that it appears like an open circuit at the resonant frequencies, as is the pad 54 at the input.

By means of leads 57, capacitive coupling is provided between electrodes 16, 17 and 18, 19. Like the arrangement shown in Fig. 9A, there are small electrode strips 46 which can be connected by wire to form inter-resonator capacitive coupling as well as grounded electrode strips 47 which control coupling.

Figs. 11A and 11B illustrate an alternative means for mounting the filter on a printed circuit board 40. In this arrangement the filter body 10 is in a metal casing 80 which is open at one side. The casing has side walls 82 which are longer than the width of the top wall 11 of the body. As a result, if the body 10 is at the upper end of the casing and the open end of the casing faces the printed circuit board, an air gap 25' is created between the side 15 of the body and the circuit board.

The casing 80 may be soldered to a conductor pattern 42' on the top of the printed circuit board or it may be glued to the printed circuit board. Also, the electrode pattern is on the side 15 of the body. A conductive layer 46' is provided on the bottom of the board 40 to cover side 15 and assure that the resonators function properly. This layer 46' is connected to the casing 80 via plated-through hole 48', conductor 42' and solder weld 44'. The size of the air gap 25' and the thickness of the board 40 control the bandwidth of the filter.

As an alternative, the effect of pattern 46' can be achieved by extending pattern 42' under the casing 80. This alternative allows the pattern 46' and plated-through hole 48' to be eliminated.

While the present invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

which the body is retained, said cavity having shoulders projecting from the inner surface that engage the body to keep the inner surface of the cover at a predetermined distance from the other side surface of the body.

16. A filter as claimed in any of the preceding claims, wherein there are four resonators, and further including a coupling electrode pattern disposed adjacent said other side surface for coupling said resonators to create a phase cancellation with signals within the body so as to form at least one imaginary zero positioned so that the shape of the pass band of the filter is substantially equivalent to that of a band-pass filter with six resonators, but without an imaginary zero.

17. A filter as claimed in any of the preceding claims, wherein the electrode pattern means is provided on the other side surface of the dielectric body.

18. A filter as claimed in claim 1, 2 or 4, or any of claims 5 to 17 when dependent on claim 1, 2 or 4, wherein the electrode pattern means is provided on an insulating plate which is disposed adjacent the other side surface of the dielectric body.

19. A filter as claimed in claim 18, wherein the electrode pattern means is provided on that surface of said insulating plate against which the body is located.

20. A filter as claimed in claim 18, wherein the insulating plate is a multi-layer printed circuit board and the electrode pattern means is provided as a conductive layer inside the multi-layer board.

21. A filter as claimed in claim 19 or 20, wherein, on the opposite side of the insulating plate from the body, at least in an area the size of the other side surface of the body, there is an electrically conductive plating that is electrically coupled to the conductive coating of the body.

22. A filter as claimed in any of claims 18 to 21, wherein the body is fastened to the insulating plate by gluing or soldering.

23. A filter as claimed in any of claims 18 to 21, wherein the body is mounted in a bracket which has been fastened to the insulating plate.

24. A filter as claimed in any of the preceding claims, wherein the first surface of the dielectric body is covered with the conductive layer, except for an area around the or each hole.

25. A filter as claimed in any of the preceding claims, wherein the electrode pattern means includes a conductive strip connected to the conductive coating and located along at least one edge of the other side surface near one of the first and second surfaces, removal of a portion of said strip adjacent the resonator being effective to change the frequency of the resonator.

26. A filter as claimed in any of the preceding claims, wherein removal of a portion of the dielectric material on the first surface adjacent a resonator is effective to alter the frequency of the resonator.

27. A duplexer filter for a radio having an antenna , a transmitter and a receiver, comprising:

first and second filters as claimed in any of the preceding claims; and

connecting means for connecting the first filter between the transmitter and the antenna, and for connecting the second filter between the receiver and the antenna.

28. A duplexer filter as claimed in claim 27, wherein the connecting means includes a portion of the electrode pattern on the other side surface.

29. A duplexer filter as claimed in claim 26, wherein the portion of the electrode pattern is an electrode strip one-quarter wavelength of the resonant frequency of the resonator in length.

30. A duplexer filter as claimed in claim 27 or 28, wherein the portion of the electrode pattern forms a reactive component.

31. A duplexer filter as claimed in any of claims 27 to 30, wherein the electrode pattern for the dielectric block of one of the filters forms the block into a band-pass filter with at least one imaginary zero.

32. A duplexer filter as claimed in any of claims 27 to 31, wherein the electrode pattern for the dielectric block of one of the filters forms the block into a band-stop filter.

33. A duplexer filter as claimed in claim 24, wherein the dielectric block of one of the filters has four holes and an electrode pattern that creates a four resonator band-pass filter with imaginary zeros at both sides of the pass-band, and the dielectric block of the other filter has three holes and an electrode pattern that creates a three resonator band-stop filter.

FIG. 5A

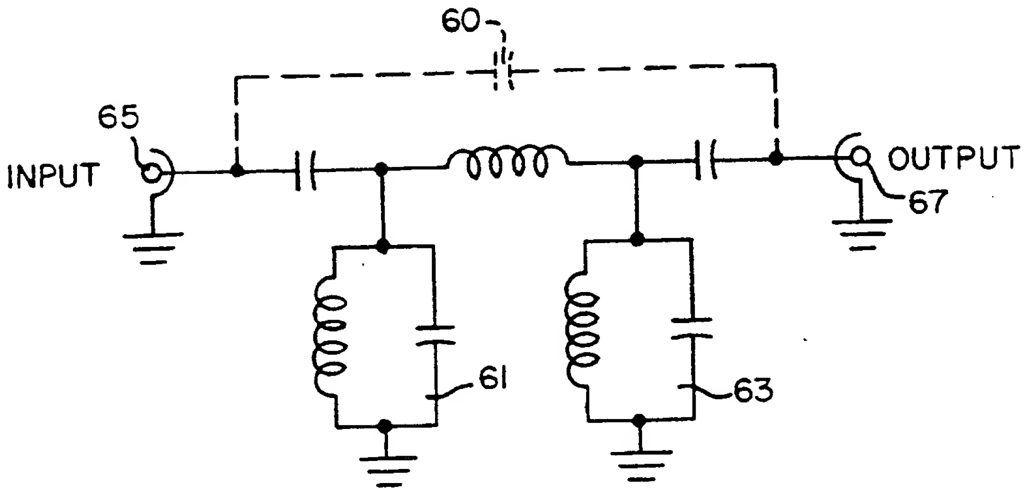


FIG. 5B

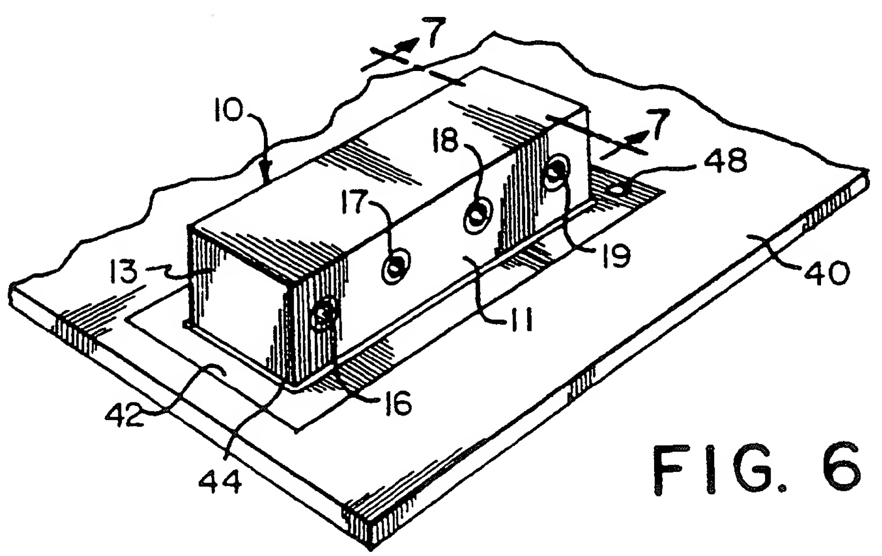


FIG. 6

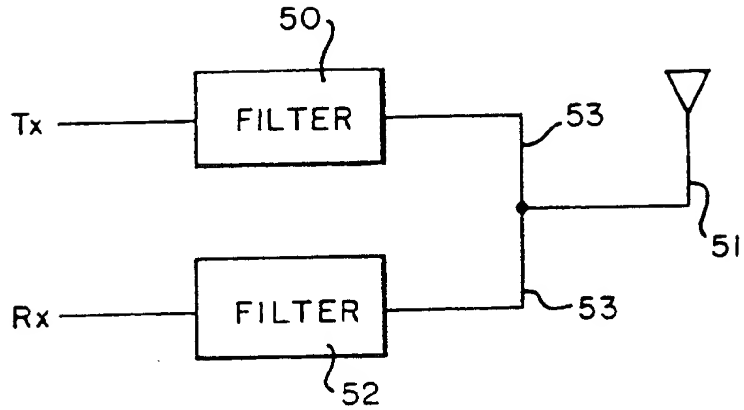


FIG. 10A

FIG. 10B

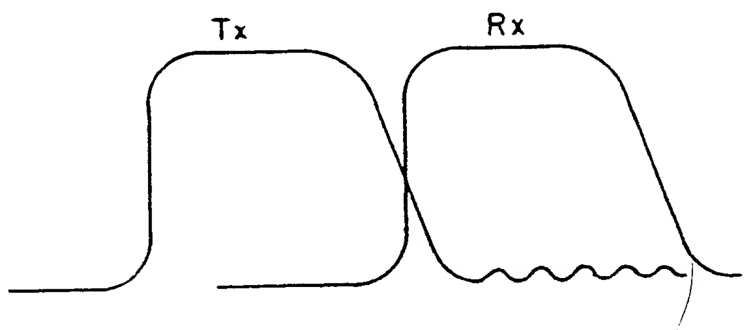
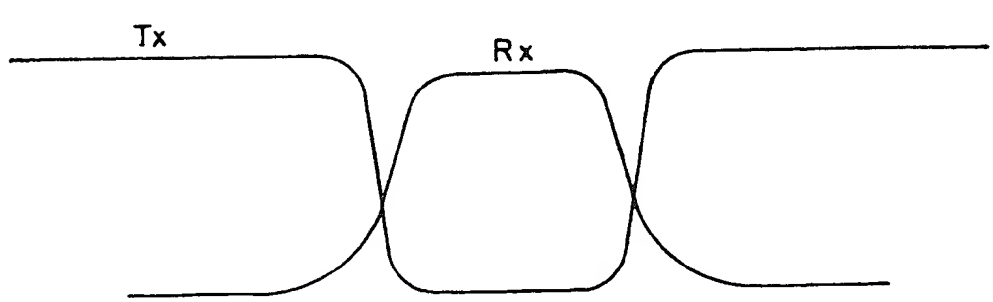


FIG. 10C



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EUROPEAN SEARCH REPORT

Application Number
EP 95 11 5737

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
X	PATENT ABSTRACTS OF JAPAN vol. 8 no. 239 (E-276) ,2 November 1984 & JP-A-59 119901 (FUJITSU K.K.) 11 July 1984, * abstract *	1,2	H01P1/205
A	PATENT ABSTRACTS OF JAPAN vol. 13 no. 254 (E-772) ,13 June 1989 & JP-A-01 053601 (NIPPON CHIYOUTANPA K.K.) 1 March 1989, * abstract *	3	
A	PATENT ABSTRACTS OF JAPAN vol. 7 no. 222 (E-201) [1367] ,4 October 1983 & JP-A-58 114503 (FUJITSU K.K.) 7 July 1983, * abstract *	1,3	
A	WO-A-88 01104 (MOTOROLA INC.) * page 7, line 33 - page 8, line 16; figures 4C,6A,B,8 *	27	TECHNICAL FIELDS SEARCHED (Int.Cl.5) H01P

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	8 November 1995	Den Otter, A

CATEGORY OF CITED DOCUMENTS

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